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13. ABSTRACT *(Maximum 200 words)*
The objective of this program is to develop a widely tunable semiconductor laser diode with an integrated wavelength monitor. During this period improvements in the device tuning range and stability have been obtained by using buried-heterostructures, and initial results with miniture, monolithic wavelength monitors have demonstrated good wavelength readout, but with some remaining problems. Techniques to solve these problems as well as alternative designs are under study. The first generation devices have also been packaged, and solvable problems were identified.

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Year End Progress Report for NRL Project on "Improved Sampled Grating DBR Widely-Tunable 1.55μm Lasers"

The goal of this program is to develop a widely tunable semiconductor laser diode with an integrated wavelength monitor. The technology development necessary for achieving this goal has been broken down into several separate tasks. These are being pursued in a three-year research program. This report documents the progress that has been made in the second year of this program since the last progress report in May 1998.

Tunable SGDBR Laser

Prior to June our best tuning results for the ridge waveguide SGDBR lasers were for 23 nm of continuous tuning. We have demonstrated that the tuning range limitation for these devices resulted from insufficient gain in the four quantum well, offset active region. To improve on this we have developed a six quantum well structure with a slightly thinner 350 nm thick 1.4 μm band gap quaternary waveguide. We have also been working on developing a buried heterostructure device to provide improved tuning efficiency and better lateral current confinement. The buried device uses a simple p-type InP regrowth over an etched ridge with a subsequent proton implant to prevent lateral carrier leakage in the cladding. This type of structure is very efficient and can be achieved in a single regrowth step.

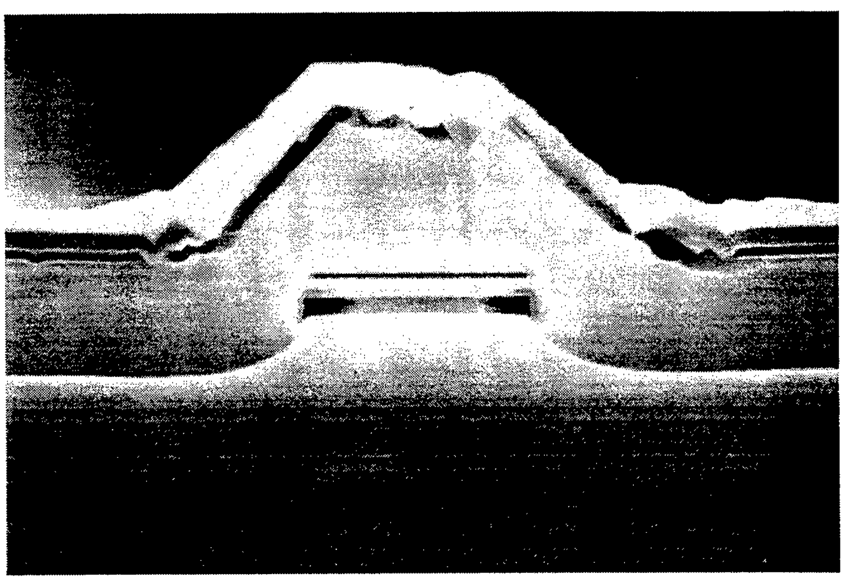

Figure 1. Scanning Electron Micropgraph (SEM) of Wet Etched Buried Ridge Structure

Two different processes have been developed for fabricating the buried ridge structure prior to regrowth. One is a wet etch using a saturated bromine water based solution that undercuts a silicon nitride ridge mask. This produces very smooth side walls on the ridge with a gradual slope transition as shown in Fig. 1. Unfortunately, the diffusion limited nature of the SBW etch leads to significant non-uniformity in the etch depth over the surface of the wafer which also translates into variations in the ridge width.

The other method is a dry etched process which uses a methane, hydrogen, argon reactive ion etcher. This method gives improved uniformity in the etch depth and the ridge width which is accurately reproduced from a silicon nitride masking layer. This technique minimizes the etch depth which reduces the regrowth step height as illustrated by the SEM in Fig 2.

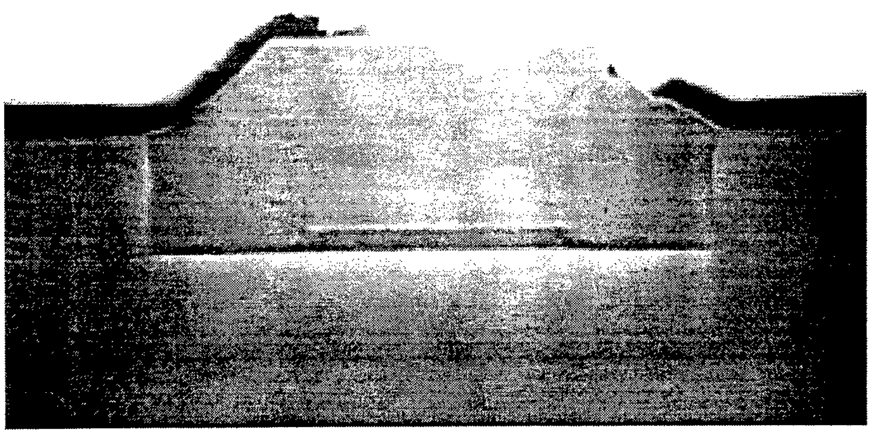

Figure 2. SEM of Dry Etched Buried Ridge Structure

The wet etched devices were fabricated without the implantation step which resulted in significant leakage currents that raised the threshold to 60 mA. Despite this, output powers of greater than 5 mW were obtained with these devices and the pulsed L-I curves showed no evidence of rollover up to 150 mA. These devices did not have good tuning characteristics since they were fabricated from material with a waveguide structure that was not optimized for tuning.

The dry etched lasers were fabricated from the optimized waveguide design with the four offset quantum well active region. As shown in Fig. 3, these lasers had excellent tuning characteristics and were capable of tuning over a range of more than 41 nm.

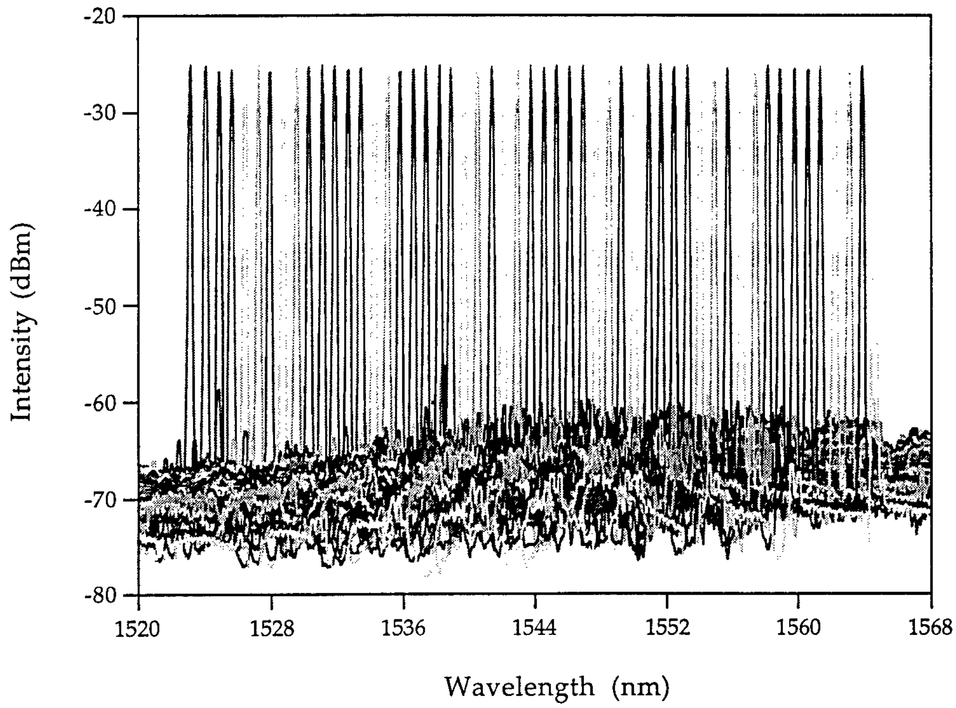

Figure 3. Buried SGDBR 41.5 nm Tuning Range

By proton implanting around the buried ridge and etching the contact layer, the lateral current leakage was dramatically reduced in this device. The threshold current dropped to as low as 15 mA which is lower than the best ridge device at 21 mA, however, the threshold current density is a little higher.

For a 3 μm wide ridge device with 22 nm of tuning range the maximum current was 52 mA into the back mirror. For the same grating design and waveguide structure the buried laser achieved 30 nm of tuning with a maximum current of only 21 mA. This is due to increased carrier confinement in the buried structure. The index change is plotted against injected current density for the ridge and buried SGDBR in Fig. 4. The buried structure has as much as 40% more index shift for a given injected carrier density because of its reduced carrier leakage. The index change in the buried device also rolls over at a higher current density due to the reduced thermal impedance of the structure.

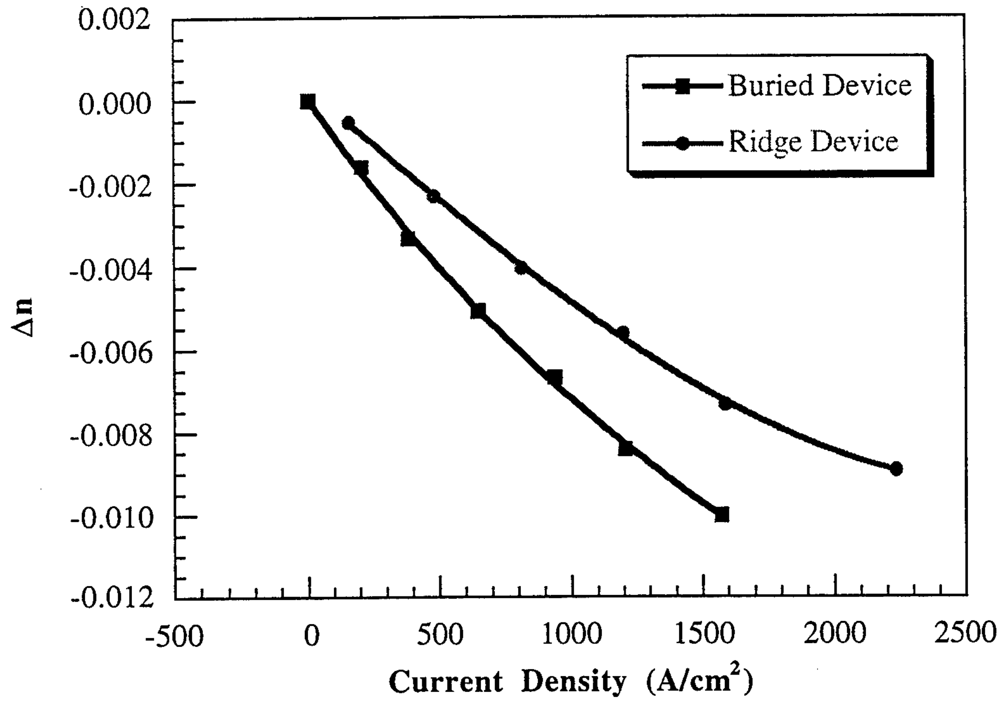

Figure 4. Index Tuning For Buried and Ridge SGDBR Mirrors

Despite the excellent lateral carrier confinement, the output powers from the buried lasers were limited by transverse leakage. This problem can be attributed to increased zinc diffusion in the thicker buried heterostructure regrowth. This increased diffusion moved the p-n junction in the active region down into the waveguide below the quantum wells. This significantly increased the transverse leakage current in the devices especially at higher bias levels. In pulsed mode operation the output power of the lasers rolled over at drive currents on the order of 100 mA with peak output powers of about 1.2 mW. To correct this problem a thicker doping setback layer is being used on the next generation of devices. We are also incorporating a six quantum well active region to increase the peak gain.

Wavelength Monitoring

The buried lasers were fabricated with two types of integrated wavelength monitors. One employed a y-branch splitter with the two mode interference waveguide to provide a wavelength sensitive response. This device worked well in the ridge configuration but could not be fabricated with the degree of precision required for the buried laser. The etching and regrowth process for the buried waveguides placed limitations on the splitter design which reduced its efficiency. Reflections from the y-branch resulted in a resonant

cavity being set up in the TMI guide. This significantly reduced the effectiveness of the wavelength monitor. The other design eliminated this problem by using a tapered waveguide and a segmented detector. Preliminary tests with the tapered wavelength monitor look promising. Electrical isolation between the two adjacent detector segments is greater than 1E5 ohms and between the detectors and the laser it is greater than 5E6 ohms. Pumping the front mirror section to 40 mA with all other sections unbiased results in a detector current of 10 nA. This current is primarily due to absorption of stray substrate light. Pumping the back mirror to a level of 40 mA results in over 100 nA of detector current. This leakage current does not change under reverse bias conditions indicating that it is optical in nature. At a laser output power of 1 mW the maximum error due to this optical leakage path will be less than 0.05%. Fixing the back mirror tuning current and varying the front mirror to cover a range of 35 nm it is possible to trace out the envelope of the wavelength monitor response curve in Fig. 5.

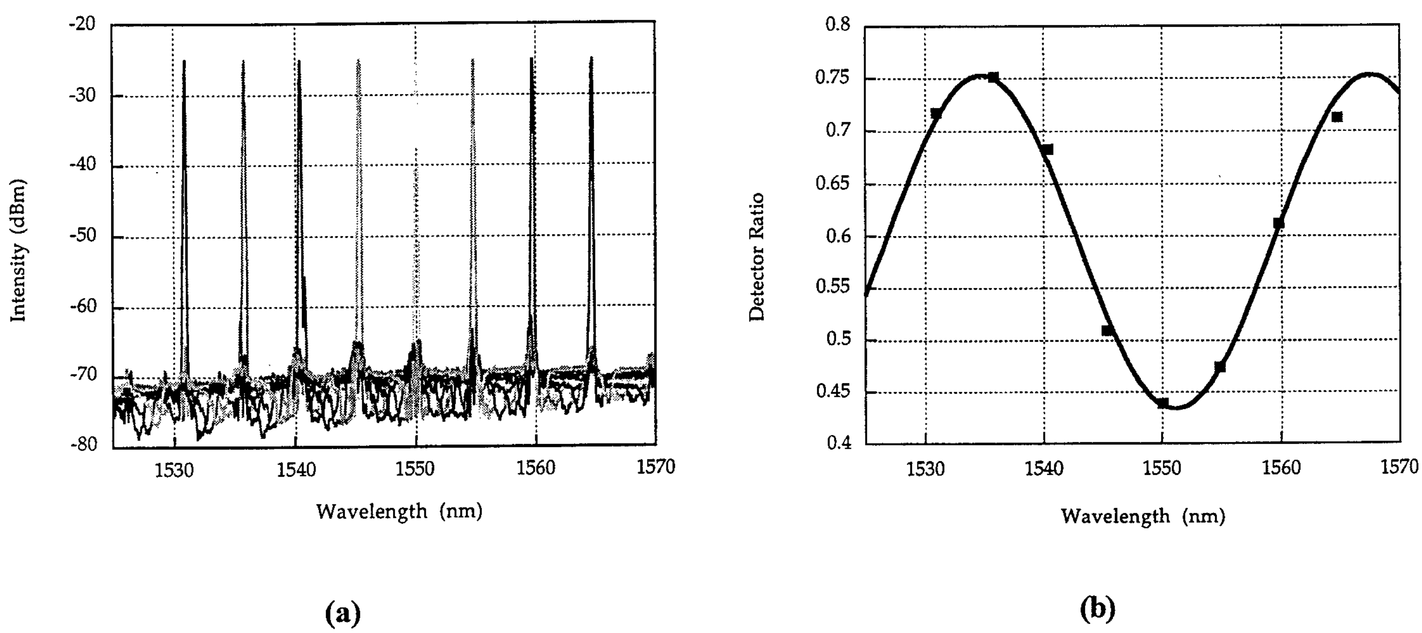

Figure 5. Wide range wavelength scan showing laser spectra (a) and wavelength monitor divided output ratio (b)

This result fits well with the theoretically predicted device performance. However, when both mirrors are tuned there is considerable variation in the response curve. After carefully repeating the test shown in Fig. 5 for several different back mirror bias currents, we determined that the pumping of the back mirror was producing a significant amount of optical energy from spontaneous emission. Much of this was being absorbed in the TMI waveguide resulting in a shift in the index of refraction and thus a change in the monitor's response curve. It may be possible to clamp the carrier density in the TMI region by

reverse biasing it to sweep out any generated carriers. Future research will concentrate on quantifying this phase response and methods to overcome it.

Device Packaging

We have just completed our first packaged device. The laser is an early ridge waveguide device with an integrated wavelength monitor. Initial trials were hampered by a lack of rigidity in the fixture which held the metallized single mode lensed fiber in place. To overcome this, a special ferrule was designed with a horse shoe clip to afix it to the package as shown in Fig. 6. The ferrule provides a ridged holder for positioning the fiber while the soldering operation takes place or alternatively an epoxy is used to fixture the fiber. Once the fiber is bonded the clip is used to attach the ferrule to the package. A tapered cap is then used to seal it and provide strain relief.

The thin film solder heaters have been tested using a 118°C solder paste. The solder melts with a bias current of 1.2 Amps applied with a pair of wafer probes. The thermal cycle time can be as low as 3 seconds from heat application to removal.

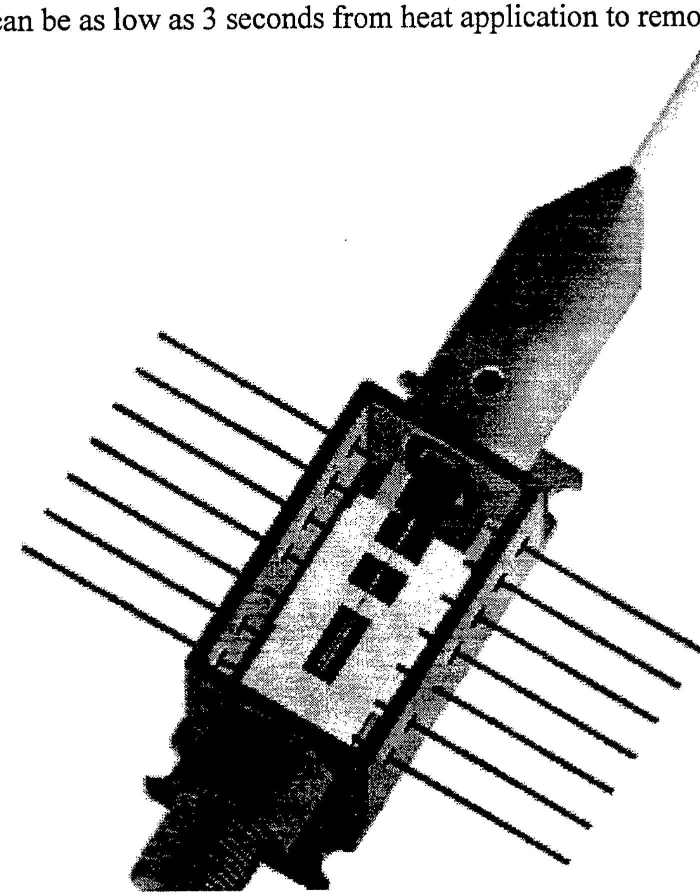

Figure 6. Interior Detail of Butterfly Package Design

The first packaged device has a threshold of 35 mA and a maximum output power of 150 μW. The low output power is partially due to a 3 dB degradation in the coupling efficiency from the optimum value which was achieved with this lensed fiber approach.

Future Work

Future work will focus on two main areas which need improvement: increased output power and tuning range from the buried heterostructure lasers, and better isolation and wavelength sensitivity in the wavelength monitors. With increased gain from the active region and reduced leakage we hope to be able to obtain much higher output powers and wider tuning ranges.

Work on the wavelength monitor will focus first on characterizing the coupling between the mirror current and the TMI response of the existing device and ways of eliminating this. In the long term we are working on developing a new wavelength monitor design which will have much lower temperature sensitivity and won't be sensitive to stray light from pumping of the passive sections.

We are currently upgrading the packaging station to an improved six axis positioner. This will enable better coupling efficiency to be achieved for the pigtailed devices. We are also working on an improved die attach method which uses a fluxless gold-tin solder process to improve the thermal heat sinking of the mounted devices.

Publications

B. Mason, G.A. Fish, S.P. DenBaars, L.A. Coldren, "Ridge Waveguide Sampled Grating DBR Lasers with 22-nm Quasi-Continuous Tuning Range," *IEEE Photon. Techn. Letts.* (USA), 10, (9), 1211-1213, (Sept. 1998).

B. Mason, S.P. DenBaars, L.A. Coldren, "Tunable Sampled-Grating DBR Lasers with Integrated Wavelength Monitors," *IEEE Photon. Techn. Letts.*, (USA), 10, (8), 1085-1087, (Aug. 1998).

Conferences

B. Mason, G.A. Fish, S.P. DenBaars, L.A. Coldren, "Sampled Grating DBR Lasers with 22 nm Quasi-Continuous Tuning and Monolithcally Integrated Wavelength Monitors," *16th IEEE International Semiconductor Laser Conference*, Nara Japan, (Oct. 4, 1998).